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A COMPARISON OF THE SENSITIVITY OF THE
TRACOMETER AND THE CRITICAL TRACKING TASK TO
ALCOHOL INTOXICATION

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ABSTRACT

The NHTSA Drunk Driving Warning System (DDWS) has recently been shown to be a potentially effective drunk driving countermeasure. It is an in-vehicle, pre-driving test device designed to detect and deter intoxicated drivers on the basis of their performance on the Critical Tracking Task (CTT). The effectiveness of the device in detecting intoxicated drivers, however, is reduced in countries such as Canada where the legal driving blood alcohol limit is lower than 1,000 mg/l. There is some evidence that another psychomotor test, ie., the Tracometer, may be more sensitive to the effects of alcohol or more reliable than the CTT. The Tracometer, a pursuit tracking task developed at the Canadian National Research Council, has been shown to be highly sensitive to alcohol, sleep-loss and other stressors. The purpose of the present experiment was to evaluate the potential of the Tracometer task for in-vehicle use.

An experiment was conducted to compare the sensitivity and discriminability of the CTT and the Tracometer at different levels of blood alcohol concentrations. Twenty subjects were tested at four BAC levels in a within-subject, balanced design. On each occasion, the subjects were tested on the CTT and the Tracometer before and after administration of the treatment.

The results indicate that the Tracometer task provides less variable baseline measures, and better discriminates dosage levels than the CTT. The major disadvantage of the Tracometer is that, currently, a single trial takes an average of 150 seconds to complete. It is recommended that further research be performed to validate these findings and to investigate methods for reducing task time.

INTRODUCTION

Between 1500 and 2000 drivers die each year in traffic accidents across seven Canadian provinces. Recent studies performed by the Traffic Injury Research Foundation (Beirness et al., 1985) found that approximately 60% of these fatalities tested positive for blood alcohol, 80% of whom had BAC levels in excess of the statutory limit for driving. In the USA, alcohol is estimated to be involved in 53-58% of fatal accidents representing about 22,500 traffic deaths in 1983 (Fell, 1983). Alcohol is unquestionably the single most serious factor in traffic fatalities.

Over the past two decades, a concerted research effort has been directed at developing in-vehicle devices to detect and deter impaired drivers. In the early 70s, the US National Highway Traffic Safety Administration (NHTSA) began sponsoring research into different approaches to the development of such devices. A variety of devices, originally known as alcohol interlocks, were proposed, ranging from vehicle-mounted breathalyzers to instruments that continuously monitored the driver's control responses while driving. Although a great deal of progress has been made in this area, no device has yet been developed which can accurately and reliably discriminate between impaired and non-impaired drivers.

Breathalyzers would provide direct measures of BAC levels; however, present technology is not sufficiently advanced to permit breathalyzer equipment to be used in vehicles without the need for constant calibration. Breathlyzers are also relatively easy to cir-

cumvent. Current efforts are focussed on the development of devices employing pre-driving tests of psychomotor performance. These devices are not intended to detect impairment of driving ability; rather they are used to detect alcohol intoxication at levels which exceed the legal limit for driving. We must be careful to distinguish between the terms impairment and intoxication. Intoxication refers to the physical state involving the presence of a measurable concentration of alcohol in the body, as measured in the blood and expressed in units of milligrams ethanol per litre of blood. Impairment, on the other hand, is the behavioural response to intoxication. It is important to recognize that the drunk driving test devices are designed to measure impairment of specific skills which is then used to make inferences of the driver's BAC level. Impaired performance on these devices is not regarded as direct evidence of impairment of driving ability. Hence, these devices are used as indicators of intoxication rather than impairment.

There are two fundamental aspects to these devices; (a) method of detection, and (b) method of deterrence. With respect to deterrence, the current emphasis is on the development of warning devices, as opposed to interlocks. It is generally agreed that such devices should function as warning devices to alert the driver, passersby and enforcement officers that the driver of the vehicle may be impaired. Disabling the ignition may not be appropriate in all circumstances (eg. in an emergency). The present study, however, was concerned exclusively with the problem of detection.

Experiments with selected perceptual-motor tasks have shown that one of the most sensitive behavioural tasks to alcohol intoxication is the Critical Tracking Task (Snyder, 1984). This task consists of a closed-loop compensatory tracking task with an unstable dynamic response. For a full description of the task, the reader is referred to the report by McDonnell and Jex (1967).

We shall use the term task in this paper to refer to the psychomotor demands placed on the subject during the performance of one complete unit of activity, or trial. The term test will be used to refer to a standardized presentation of one or several tasks and a scoring procedure to derive a quantitative measure of skilled performance.

Continued research into the CTT led to the development (by Systems Technology Incorporated of California) of the Drunk Driving Warning System (DDWS). The most recent version of the DDWS requires that the test be taken and passed prior to operating the vehicle. Test performance is compared with individualized sober performance. In the current configuration of the DDWS, the pass criterion level is set at the 40th percentile of the mean trained sober performance. The driver is given 4 tries to pass the test. If he fails the session, he must wait 10 minutes before trying again. If the driver attempts to drive the vehicle without having passed the test, the system will cause the vehicle emergency lights to flash and, at speeds above 10 mph, the horn to sound intermittently.

The DDWS has undergone extensive testing and validation (Allen et al., 1983a and 1983b). The pass/fail criteria was selected to produce a sober failure rate of 2.5%. Using this criterion, the DDWS was found to produce a failure rate of 35-40% at a BAC level of 1000 mg/l and of 75-80% at a BAC level of 1500 mg/l. The results of a field test (Allen et al., 1983b), involving persons habitually convicted of driving while impaired, confirmed that the DDWS has considerable potential as drunk driving countermeasure, though certain problems related to hardware design and scoring strategies appear to require further research and development.

In Canada, the legal driving blood alcohol limit is 800 mg/l BAC rather than 1000 mg/l BAC in use in the USA. This reduced driving BAC limit would render the DDWS less effective in Canada as a test of intoxication due to the decreased sensitivity of the test at this lower BAC limit. A recent evaluation of the DDWS in Australia, for example, concluded that the device was unacceptable for use in that country because of its poor discriminability at BAC levels of 500 mg/l (the legal limit in Australia). Hence, a more sensitive test of alcohol appears to be required for countries such as Canada and Australia to achieve detection rates comparable to the findings in the USA.

A psychomotor test known to be sensitive to the effects of alcohol is the task embodied in the National Research Council's (NRC) Tracometer. The Tracometer is a device designed to investigate the effects of a variety of stressors on psychomotor performance. Unlike the CTT which is a compensatory tracking task, this task is a pursuit tracking task. The device provides measures of correct reaction time,

acquisition time, overshoot movement time, error score and overshoot score as well as total response time to complete the 100 movements. A more detailed description can be obtained in Buck (1981, 1982, and 1983).

Several investigations have shown that the Tracometer is sensitive to such factors as sleep loss (Buck, 1974), alcohol (Carpenter et al., 1975, and Beirness et al., 1980), and insulin-induced hypoglycaemia (Fraser et al., 1974), demonstrating the usefulness of the device in examining behavioural effects of drugs and other stressors.

Because of its demonstrated sensitivity to alcohol and other drugs, it is believed that the Tracometer may be better able to detect alcohol intoxication than the CTT, though no direct comparative data exist. The only comparative study of the two tasks examined two different methods for administering marijuana on psychomotor tracking (Noy and Smiley, 1984). The results indicated that the Tracometer was more sensitive than the CTT to the effects of marijuana.

The purpose of this study was to explore the potential of the Tracometer task for detecting alcohol intoxication. Specifically, the study was designed to compare, in a controlled experiment, the sensitivity of the Tracometer and the CTT to alcohol intoxication at 0, 500, 800 and 1000 mg/l BAC and to compare the ability of these tests to discriminate between intoxicated and non-intoxicated individuals.

METHOD

Experimental Design

The experimental design was a one-way within-subject, balanced design using two independent tests. Twenty subjects were given four alcohol treatments individually prepared to achieve blood alcohol levels of 0, 500, 800 and 1000 mg/l BAC. These dose levels are commonly used because they relate to statutory levels. Treatment order and dose levels for any given day were balanced using five 4X4 latin squares, as shown in Table 1. Day 0 was used to designate the day on which training occurred. The CTT test consisted of 20 trials while the Tracometer test consisted of 4 trials. Although the tests were not matched for number of trials, the tests received equivalent exposure (15 minutes per test). Test order was balanced to control for test order effects (the first test taken by each subject is shown in the right-most column of the Table 1). For each subject, alcohol dosing and testing occurred at the same time of day. Subjects were tested both before and after dose administration.

Figure 1 depicts the sequence of tests and alcohol administration for a typical subject. This subject was given the CTT tests first.

FIGURE 1: Test Sequence

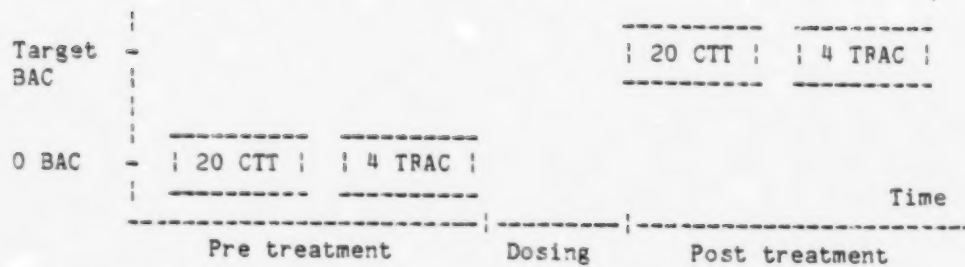


TABLE 1: Subject-Treatment Assignments (BAC)

S	DAY					Test Order
	0	1	2	3	4	
A	T	.00	.05	.10	.08	Trac
B	T	.10	.00	.08	.05	CTT
C	T	.05	.08	.00	.10	Trac
D	T	.08	.10	.05	.00	CTT
E	T	.08	.05	.00	.10	Trac
F	T	.10	.08	.05	.00	CTT
G	T	.00	.10	.08	.05	Trac
H	T	.05	.00	.10	.08	CTT
I	T	.00	.10	.05	.08	Trac
J	T	.05	.00	.08	.10	CTT
K	T	.08	.05	.10	.00	Trac
L	T	.10	.08	.00	.05	CTT
M	T	.00	.10	.08	.05	Trac
N	T	.08	.05	.00	.10	CTT
O	T	.05	.00	.10	.08	Trac
P	T	.10	.08	.05	.00	CTT
Q	T	.08	.05	.00	.10	Trac
R	T	.10	.08	.05	.00	CTT
S	T	.08	.05	.00	.10	Trac
T	T	.10	.00	.08	.05	CTT
U	T	.00	.10	.05	.08	Trac
V	T	.05	.08	.10	.00	CTT

Performance Tests

(i) Critical Tracking Task

The CTT was implemented in the present experiment using an oscilloscope and a joystick. The task was controlled by a PDP11/34 computer running RT-11. A bright horizontal line was displayed to the subject on the cathode ray tube. At the start of the trial, the line began to drift erratically up and down about the centre position and the subject was required to return it to the centre of the tube using the joystick. The subject's task was made increasingly difficult as the test progressed through software control until he could no longer control the displayed element. The test score, λ , was a direct measure of the difficulty level (a variable controlled by the software algorithm) at which control of the line was lost. This score represented the maximum performance limit for that subject and provided an indirect measure of the subject's "effective delay time" (in control theory, the term used to denote the time lag introduced by a human operator). A test session consisted of 20 trials (about 15 minutes).

Although the implementation of the CTT in the present experiment differs from the implementation in the DDWS, the dynamics of the task (eg., rate of divergence and controlling functions) were identical. Because both tasks fundamentally measure a quantity related to effective delay time, the differences in hardware are not likely to produce significant differences in results.

(ii) Tracometer

The Tracometer was on loan from the NRC. The task itself was a step-input, subject-paced, pursuit tracking task. The subject was seated in front of the display unit which presented five target positions (small lights). At the start of a trial one target was illuminated. The subject's task was to align the pursuit pointer with the target using a control wheel. The control wheel was connected in such a way that it had to be turned in a direction opposite to the desired pointer movement. Once the pointer was accurately aligned with the target for a period of 200 msec., the light was extinguished and a new target appeared at random at one of the other four positions. One trial consisted of 100 consecutive repetitions of this task arranged in five blocks of 20 repetitions. Each block presented all possible movements between targets. The subject was instructed to complete the 100 movements as fast as possible. The score used for Tracometer performance was the total time taken (in seconds) to complete a trial. For a more detailed description of the Tracometer see Buck et al. (1981, 1982, and 1983). A test session consisted of four trials taking approximately 15 minutes to complete.

Subjects

Twenty male subjects between the ages of 19-30 years were selected from respondents to newspaper advertisements. They were screened on the basis of a drug use questionnaire to eliminate regular users of psychoactive drugs and to ensure that they were moderate drinkers as

defined by the Cahalan, Cisin and Crossley quantity-frequency scale of alcohol use (Cahalan et al. 1969). Subjects were rated as moderate-light (drinking code 1), moderate (drinking code 2) and moderate-heavy (drinking code 3) drinkers. Subject interview forms are provided in Appendix A.

Subjects eligible to participate in the study were required to undergo a medical examination to ensure that they were medically fit and not taking any medication. During the medical examination, each subject's weight and skinfolds were measured. Skinfold measurements were taken at the triceps, the sub-scapular and supra-iliac sites. Subjects who were accepted for the study were asked to sign a consent form to indicate that they understood the purpose and requirements of the study and were willing to participate. The medical form and subject consent form are also provided in Appendix A. The skinfold measurements were used to calculate the subject's fat composition which in turn was needed in the calculation of the individual alcohol doses. The method for calculating fat percentage from skinfold measurements is provided Appendix B. Subject demographic data are provided in Table 2.

TABLE 2: Subject Demographic Data

<u>Subject</u>	<u>Age</u>	<u>Weight (lbs)</u>	<u>%Body Fat</u>	<u>Drinking Code</u>
A	22	174	21.2	2
B	23	162	16.8	3
C	29	163	15.9	3
D	24	172	22.1	1
E	27	160	22.4	1
F	19	223	26.8	3
G	30	155	21.5	3
H	19	157	15.4	3
J	22	140	22.4	1
K	22	156	17.9	1
L	25	162	23.6	1
M	20	140	15.9	1
N	22	168	14.3	2
P	20	150	15.0	3
Q	19	115	13.1	1
R	24	148	11.6	2
S	25	157	22.4	1
T	19	129	13.2	3
U	20	140	17.2	1
V	24	161	11.2	3

During the study, subjects were required to abstain from consuming the following substances: marijuana for a period of one week prior to testing; caffeine and food for 4 hours prior to testing; and, tobacco for 1-2 hours prior to testing. They were paid approximately \$25.00 for each day.

Procedures

(i) Training

Each subject was trained on the CTT and the Tracometer during a two-hour training session on the day prior to the first treatment. Subjects completed 40 trials on the CTT in blocks of 5, and 8 trials on the Tracometer in blocks of 4. To avoid massed practice effects, subjects alternated between tests, performing half of the training trials on one task, switching to the other, and so on. During training only, subjects were given feedback at the end of each trial and encouraged to improve their performance.

(ii) Testing

Each subject arrived at the laboratory approximately 90 minutes prior to treatment. A breathalyzer reading was taken to ensure that he had 0% BAC. He then performed the two tests in the order assigned. The CTT test consisted of 20 trials whereas the Tracometer test consisted of 4 trials.

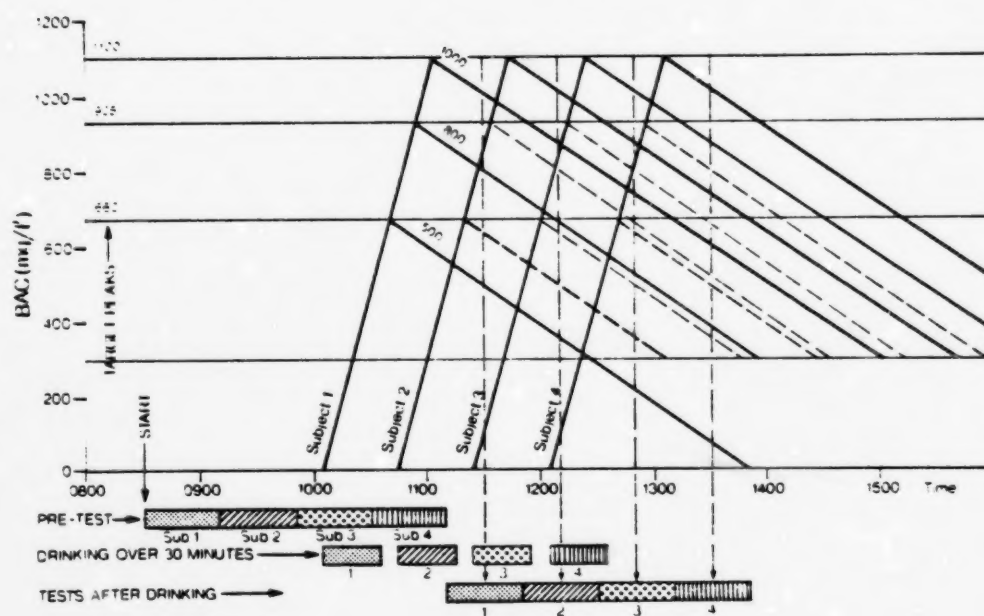
Upon completion of the pre-treatment session, the subject was administered the alcohol treatment. Subjects were not informed about the amount of alcohol they would receive. Three drinks of vodka and orange juice were given at equal intervals over a period of 30 minutes. The drinks had been measured earlier the same day for the subject on the basis of his gross body weight and fat composition using the algorithm provided in Appendix C. The dosing algorithm was de-

signed to raise the subject's BAC to a peak blood alcohol level which was in fact higher than the target BAC level. The peak BAC levels were calculated, taking into account the kinetics of alcohol distribution and elimination, to achieve the desired BAC at given times. Peak levels of 660, 925 and 1100 mg/l were thus used in an attempt to achieve target BACs at the midpoint between tests of 500, 800 and 1000 mg/l, respectively. Drinks for the placebo condition consisted of orange juice and a teaspoon of vodka floated on top. The vodka was added to the orange juice just prior to being given to the subject. Subjects were not told how much alcohol they would be receiving during treatment and most could not distinguish the placebo from an active dose, though they could discern that the alcohol treatment was a stronger drink than the placebo.

Thirty-five minutes after the end of the dosing period (ie., five to ten minutes after the expected peak BAC), the subject completed the post-treatment session consisting of 20 trials on the CTT and 4 trials on the Tracometer, in the prescribed order. These tests were performed on the down slope of the BAC/time curve.

Four subjects were treated each test day. Figure 2 depicts the daily test protocol, showing pre and post treatment sessions, treatment times and the expected time history of subjects' BAC. Three possible BAC curves are shown for each subject corresponding to the three possible active treatments. As mentioned previously, the peak BAC levels were higher than the target levels to allow the BACs to reach

Figure 2: Experimental Protocol



the desired levels at the appropriate time on the declining BAC curve. Breathalyzer readings were taken immediately before testing and periodically after testing to chart the rise and fall of BAC.

Subjects received lunch at the completion of the tests and remained at the laboratory for about 3.5 hours post drinking. This is roughly the time required for the blood alcohol level to fall from a level of 1000 mg/l to less than 300 mg/l BAC, considered a safe level to release subjects on their own recognisance. Subjects were driven home after their blood alcohol concentration had been confirmed by the breathalyzer to be below 300 mg/l.

RESULTS

Missing Data

Twenty subjects were tested over the five week experimental period. During the first week of the experiment, the CTT equipment malfunctioned, resulting in missing data for this test for four subjects. Hence, CTT data were obtained for only 16 of the 20 subjects. Although this created unequal N's for the two tests, it did not compromise the design in any way since the missing data affected only one of the five latin squares. Analysis of the CTT data was, therefore based on observations for four groups of subjects (each group balanced with respect to test order and day).

One subject, S, displayed gross impairment following treatment at the 1,000 mg/l dose level, to the extent that he could not perform either of the tests (or sit in a chair unassisted). None of the other subjects displayed any obvious signs of impairment even at the high dose condition.

Baseline Data

The pre-treatment data were analyzed to test for learning effects across days and trials. Analyses of variance indicated the presence of significant Day effects for both tests. For the Tracometer, Trial Number was also a significant factor.

Examination of least squared means for the Day effect, shown in Table 3, indicates that performance improved across the four days for both tests. Unfortunately, the training data were not recorded and it was not possible to confirm that subjects had not reached asymptotic levels at the end of training. It is apparent from the baseline data, however, that insufficient training was provided to achieve asymptotic levels and that learning continued to take place throughout the experimental period. Moreover, examination of the data revealed that for the Tracometer learning may have occurred even across trials.

TABLE 3: Day Effects

DAY	LSMEANS	
	TRAC	CTT
1	150.53	4.109
2	145.24	4.339
3	141.13	4.544
4	140.58	4.617
Mean	144.37	4.402

To minimize the variability between subjects, difference scores (ie, the difference between post treatment and pre treatment measures for the particular subject) were calculated and used in subsequent analyses of the effects of alcohol and comparisons of the tests. Moreover, because baseline levels improved throughout the four test

were used in calculating the difference scores.

The baseline data of both tests were compared for inherent reliability. Stability of the data after accounting for systematic variation due Subject, Day and Trial factors were compared using R-Square statistics from the analysis of variance. The R-Squares for the Tracometer and CTT were 0.81 and 0.56 respectively. This indicates that the baseline data for the Tracometer were more stable.

Achieved Blood Alcohol Levels

Regressions of observed BAC with time confirmed the linearity of BAC time histories in the terminal elimination phase as would be predicted by the zero-order pharmacokinetics of ethanol. The mean rate of elimination was 200 mg/l/hr. The regression equations were used to determine the subjects' BAC levels during the tests.

Table 4 provides a summary of actual BAC levels achieved for each of the four target BACs used in this experiment, pooled across both tests. The correlation between achieved BAC levels and target BAC levels confirmed the accuracy of the dosing algorithm ($r = .98$). There was a tendency towards consistent overdosing, though there was one subject, H, who showed remarkable variability (-25.8 to 33.8 %) of observed versus predicted BACs.

TABLE 4: Actual and Target Blood Alcohol Levels

Target BAC	N	Mean BAC	SD	Range
0	20	0	0	0-0
500	20	560	57	425-707
800	20	827	84	554-998
1000	19	1006	80	806-1316

Because observed BAC levels in some cases crossed treatment conditions (ie., there was some overlap of the ranges of BAC between adjacent treatment conditions), further analyses for alcohol effects employed actual observed BAC levels as the independent variable rather than treatment condition. The actual blood alcohol levels at the time of each test were calculated (for the midpoints of the test trials) from linear regressions of individual subjects' observed BAC levels with time during the alcohol elimination phase of each test day. Since the rate of alcohol elimination from the body is constant for each individual, assuming that renal excretion is negligible by comparison to metabolic transformation, the regressions provided reasonably accurate estimates of actual blood alcohol levels.

It should be noted that this procedure was used to determine the actual BACs for each test separately. Hence, while the CTT and Tracometer test were administered to a given subject one immediately after the other, the difference in the time of testing resulted in somewhat different BACs for the tests. The reader is reminded that test order was balanced to control for systematic effects on the data.

Sensitivity to Alcohol

(i) Dose-Response Relationships

Difference scores were calculated for each subject using daily mean pre-treatment scores as baseline levels. Figures 3 and 4 plot the dose-response data and linear regression models for the Tracometer and CTT, respectively. Other models were attempted without much improvement in the resultant fit. Regression analyses of difference scores versus actual BACs produced correlation coefficients for the Tracometer and CTT of .62 and .35, respectively. The correlations were highly significant indicating that both tests were sensitive to the effects of alcohol, though it is evident that there was considerable variability in the data. Tracometer performance was, therefore, found to be a better predictor of alcohol intoxication than CTT performance because higher correlations with BAC were obtained.

(ii) Placebo Effects

T-tests comparing pre and post-treatment means were performed to test for placebo effects. No significant differences were found at the .05 level between the mean post-treatment scores and the mean pre-treatment scores for either the CTT or the Tracometer for subjects receiving placebo alcohol. Hence, it was concluded that there was no placebo effect.

FIGURE 3: Mean Tracometer Difference Scores as a Function of BAC

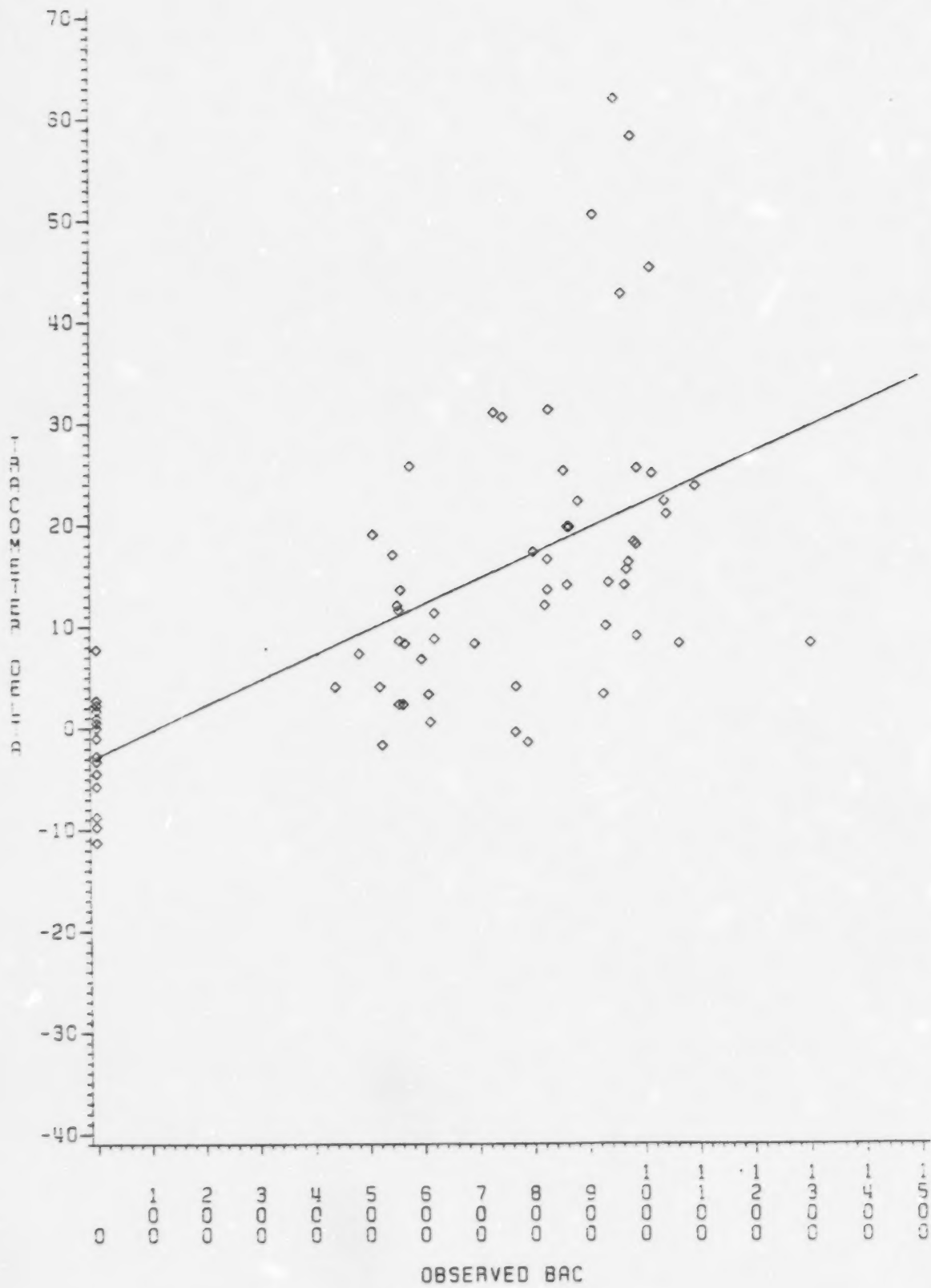
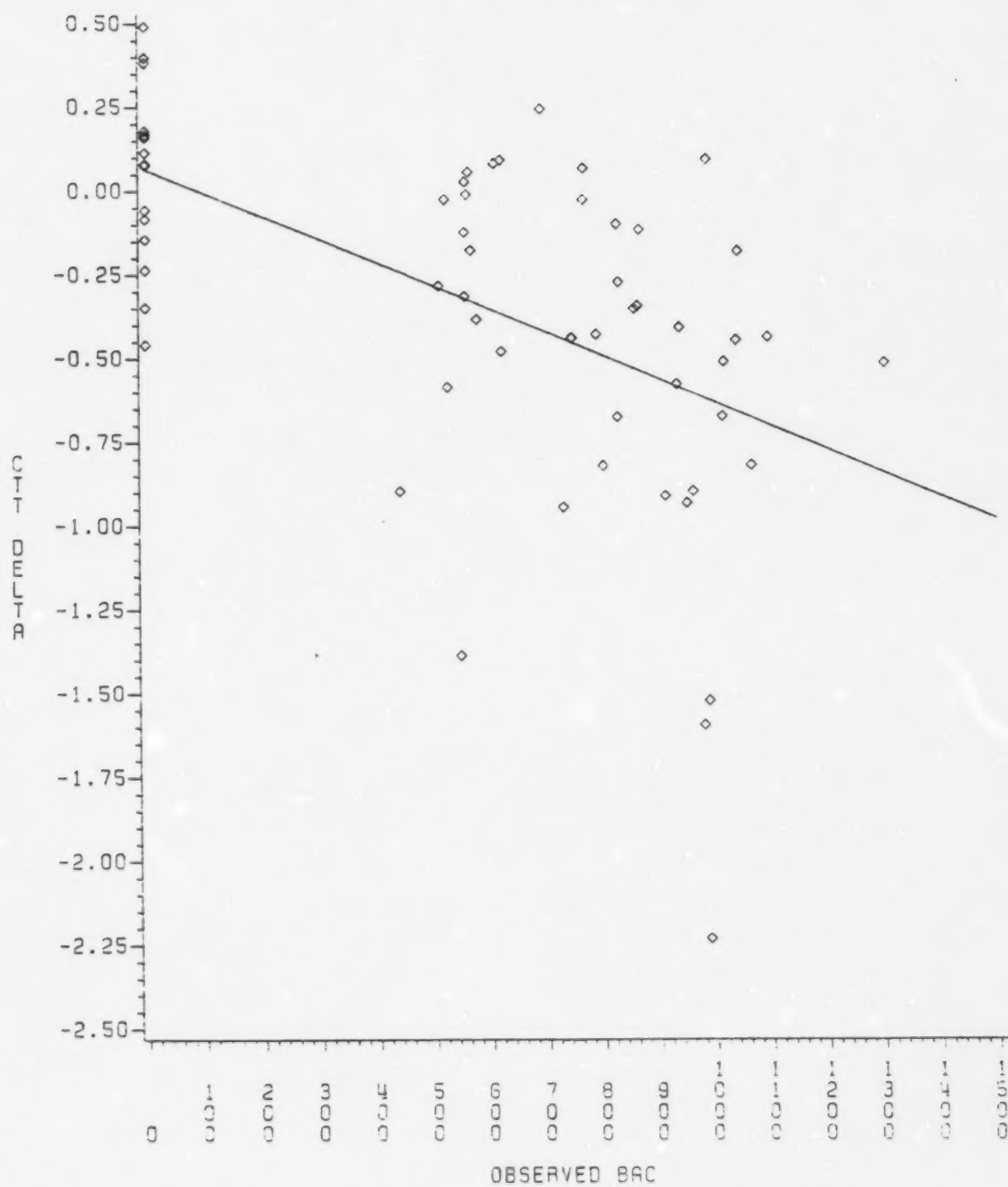


FIGURE 4: Mean CTT Difference Scores as a Function of BAC



(iii) Effects of Alcohol Tolerance

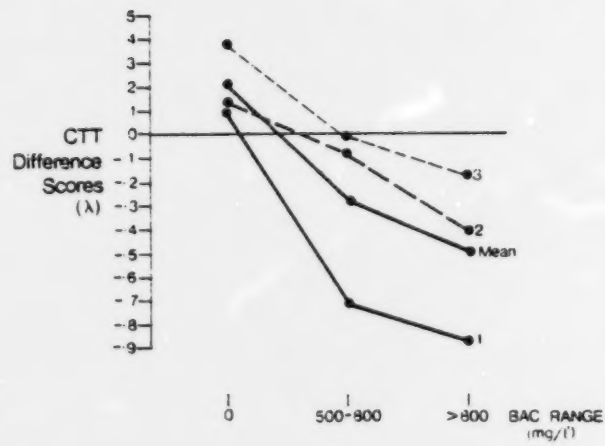
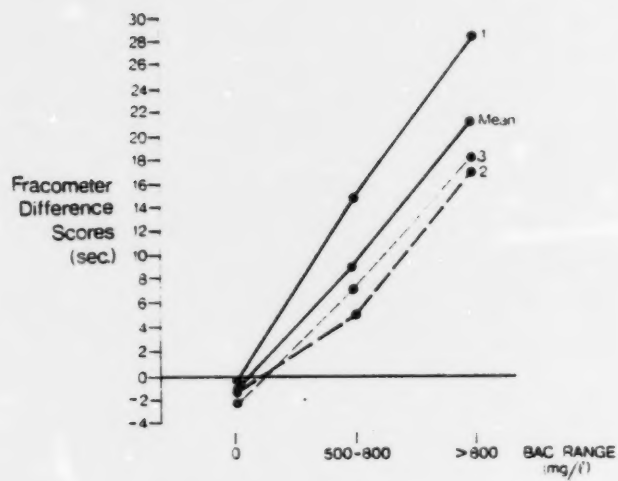
It is well known that there are wide individual differences in behavioural response to alcohol. Tolerance to alcohol may result from a number of factors, the most common being regularity of use. To examine the effects of chronic alcohol tolerance on the data, subjects were divided into three groups of alcohol use using the drinking codes described earlier. Table 5 provides a summary of these data.

Analyses of variance indicated that drinking code was a significant factor of performance ($p < .0001$), accounting for about 5% of the variance. Figure 5 plots the mean difference scores for each test as a function of BAC range by drinking code as well as the overall means. A Duncan Multiple Range test indicated that for both the Tracometer task and the CTT, the light drinkers were significantly more affected by alcohol than the moderate and moderate-heavy drinkers.

TABLE 5: Mean Difference Scores
By Drinking Code

CODE	N	000		500-800		> 300	
		TRACOMETER	CTT	TRACOMETER	CTT	TRACOMETER	CTT
1	9	-0.3125	0.098	15.18182	-0.717	28.45833	-0.888
2	3	-1.08333	0.129	5.8125	-0.092	17.7	-0.407
3	8	-2.625	0.396	7.5	-0.004	18.5	-0.197

Figure 5. Tolerance Effects



Discriminability of the Tests

The main purpose of this study was to compare the ability of the Tracometer and CTT to discriminate between individuals with BACs in excess of the statutory limit of 300 mg/l and those below the limit. The Tracometer was found to be more sensitive to alcohol; however, this does not necessarily imply that it can be more discriminating at 300 mg/l BAC.

To compare the discriminating power of the two tests, the data were divided into three categories by ranges of actual BAC levels: (a) 0 mg/l, (b) 500-800 mg/l, and (c) >800 mg/l. One subject, M, was excluded from the analysis because his difference scores for the placebo condition (BAC=0) were inexplicably high. Frequency bar charts for difference scores for BAC levels of 0, 500-800, and >300 mg/l are provided in Figures 6 and 7. These figures clearly indicate that the difference scores were distributed about the 0 level for the 0 BAC condition. Shifts in these distributions occurred for higher levels of BAC. These figures also indicate, however, that there was considerable overlapping in the distributions. Hence, while there is a clear alcohol effect, the overlap of the scores distributions at 0 mg/l and >800 mg/l could produce unacceptable levels of type I (false negatives) or type II errors (false positives) using simple pass/fail criteria.

FIGURE 6: Distribution of Tracometer Difference Scores

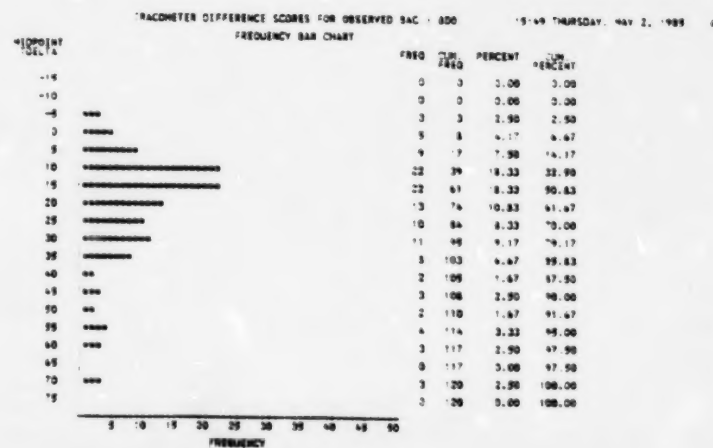
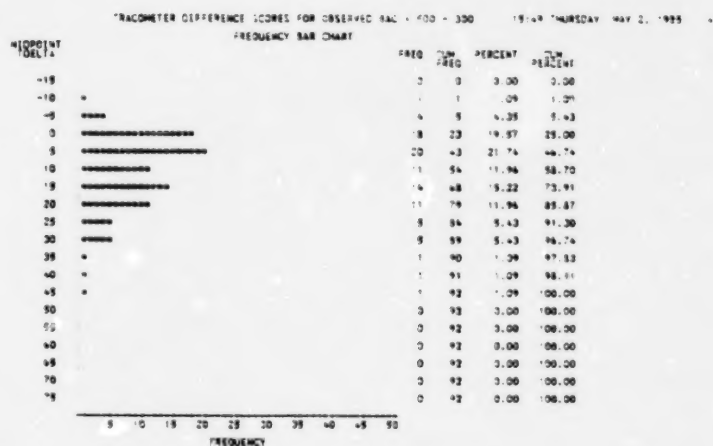
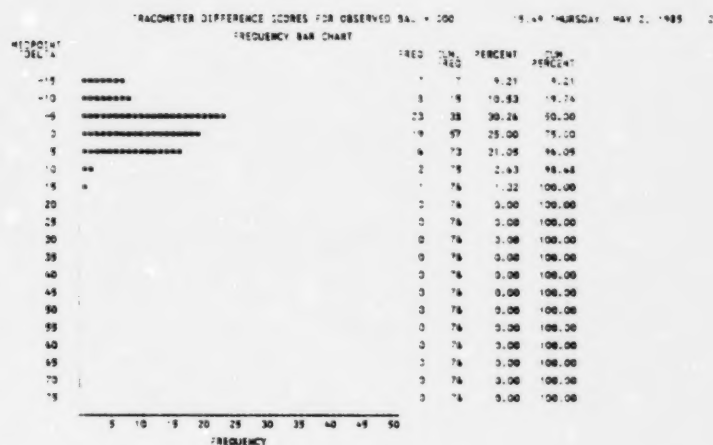
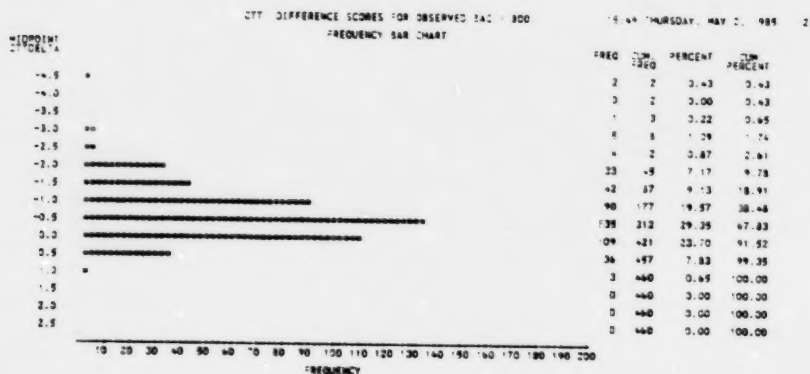
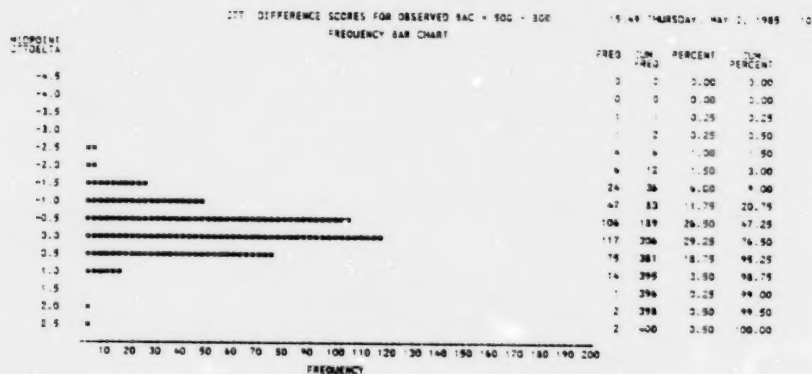
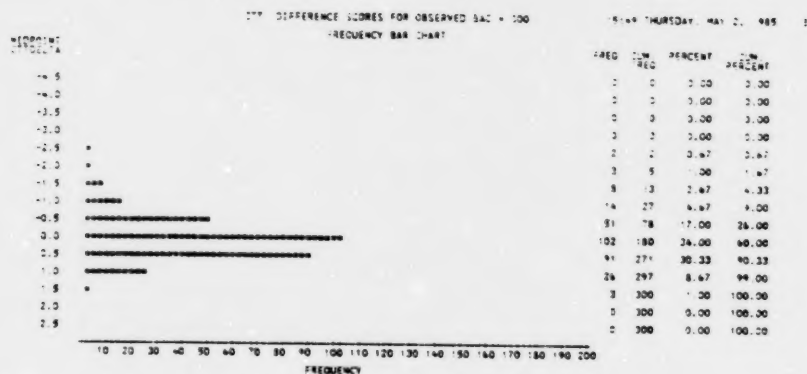


FIGURE 7: Distribution of CTT Difference Scores



To maximize test discriminability, a method for overcoming some of the variability in the data was required. One approach to reducing within-subject variability in test performance is to allow the driver multiple tries and impose a relatively more stringent pass/fail criterion. If after several attempts, the driver is not able to reach the criterion level of performance then he would be considered impaired. However, the danger with this approach is that it also provides greater opportunities for misses since the driver may perform better than expected on one of the trials and pass the test.

In order to compare the abilities of the tests to discriminate between impaired and sober drivers, it was necessary to (a) select a protocol for administering the test (or test strategy), and (b) determine a method for calculating individualized pass/fail criteria.

(a) Test Strategy.

Test strategy refers to the manner in which the test is administered. The strategy includes parameters such as how many tries are allowed, how the multiple scores are to be combined, how many tries must be passed, etc. The US studies of the DDWS/CTT examined a variety of test strategies and concluded that the optimal strategy for the DDWS was one pass in four tries. This was known as a one in four strategy. That is, the driver passed the test if on any one try his score exceeded his individualized criterion score. A maximum of four tries were allowed to obtain a pass. Because of the extensive work done in the USA to develop this strategy it was adopted for the present study as the CTT test strategy.

A similar test strategy had to be developed for the Tracometer. The overriding factor in considering alternative strategies for this test was that one Tracometer trial consisted of 100 movements and took an average of 150 seconds to complete. Hence, a Tracometer trial took about 5 times longer to complete than a CTT trial. It was not technically possible to alter the Tracometer test to make it more comparable in terms of exposure and strategy to the CTT. It was clear, however, that it would be unacceptable for the ultimate test to take more than a few minutes. For this reason, the maximum number of tries allowed was set at two. Hence, the Tracometer strategy was a one in two strategy. It should be noted, however, that The Tracometer scores were less variable and hence, a more stringent strategy (one in two as opposed to one in four) did not necessarily render the test more difficult to pass.

(b) Pass/Fail Criteria

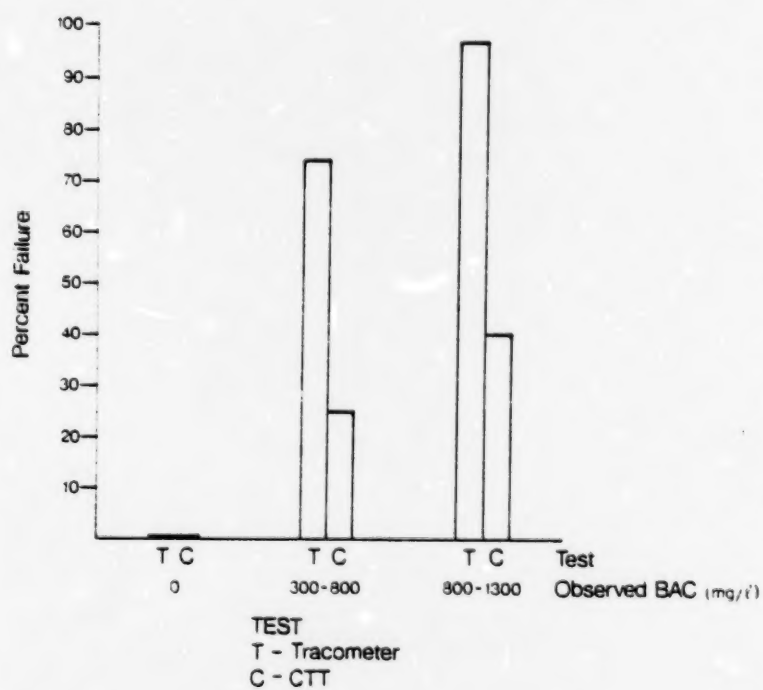
A number of different methods for calculating individualized pass/fail criteria were considered. Arbitrarily, the pass/fail criterion was defined as the value of the difference score which would just pass all of the subjects having a BAC level of 0 mg/l (eg., for the placebo subjects) using the test strategies described above. This approach ensured that both tests would have a zero failure rate for completely sober subjects. Using this approach, the pass/fail criteria obtained from the data were as follows:

Tracometer Difference Score > 1.25

CTT Difference Score < -1.5

Test failure rates were determined for the two tests by applying the test strategies and pass/fail criteria described above. Figure 3 shows the failure rates for subjects having BACs in the ranges 500-800 mg/l and above 800 mg/l. The failure rate for the placebo group was 0% for both tests. It can be seen that above 800 mg/l BAC, the Tracometer failed about 97% of the subjects whereas the CTT failed only 40%. In the range of 500-800 mg/l BAC, the Tracometer failure rate was 74% compared to the CTT failure rate of 25%. The high failure rate obtained with the Tracometer in this BAC range may be unacceptably high since in most provinces driving is not necessarily prohibited at these levels. It should be noted, however, that the Tracometer did not fail anyone with 0 mg/l BAC (as this was the basis for the criterion). Unfortunately there were extremely few observations at BAC level between 0 and 500 mg/l. Hence, it is not known what proportion of subjects would have failed at BAC levels below 500 mg/l.

Figure 8: Failure Rates for Tracometer and CTT



DISCUSSION

The CTT test results obtained in this study compare favourably with results reported in other studies. The dose-response relationship is similar in regards to the range of scores obtained and the mean performance decrement at 1000 mg/l observed. The 9% decrement in performance reported by Allen (1983a) is approximately equal to our finding of a score reduction of 0.5. Furthermore, the discriminability of the CTT using the strategy developed in the US yielded very similar failure rates - about 40% at the 1000 mg/l BAC level. However, although the effects of alcohol were clearly evident, there was considerable variability in the data. The CTT failure rate is not considered acceptable at moderate levels of alcohol since there is less than a 50-50 chance of failing the test when the criteria are designed to limit the sober failure rate to less than 2%.

The Tracometer task, by comparison, was found to be more stable, producing more consistent baseline data. This task was also more sensitive to alcohol in that it yielded higher correlation coefficients and it produced higher failure rates at moderate levels of BAC using a one in two test strategy. In fact, the failure rate achieved at levels above 800 mg/l was extremely good, nearly 95%.

However, there were also high failure rates observed at the 500-800 mg/l range. Failures in this range should not necessarily be considered as false positives. In Ontario, for example, it is a violation of Provincial laws to drive with BAC levels above 500 mg/l.

Hence, the Tracometer would be useful in detecting this group of drivers as well. The true false positives would be the test failures at BAC levels between 1 and 500 mg/l. Unfortunately, there were too few observations to determine the failure rate in this range. At 0 mg/l, the failure rate was zero.

It is not entirely clear why the Tracometer performed better than the CTT. The main difference between the tasks was that the Tracometer was a pursuit tracking task whereas the CTT was a compensatory tracking task. It is generally accepted that pursuit tracking involves higher order cognitive processes than compensatory tracking. Hence, one may postulate that alcohol has a relatively more impairing effect on higher order cognitive functions. This has also been claimed by other researchers.

It is important to recognize that an opportunity exists for the Tracometer test, to relax the pass/fail criteria if the failure rate at BAC levels below 800 mg/l were considered too high. Of course, this would also reduce the failure rate for drivers above 300 mg/l. Nonetheless acceptable failure rates for legally-impaired drivers may still be obtained. This opportunity does not exist for the CTT test since the failure rate at BAC levels above 800 mg/l (40%) was already too low.

Although this study was not designed to examine the full implications of chronic alcohol tolerance on such tests, the data suggest that performance on the tests is affected by one's history of alcohol

result in higher proportions of misses for the heavy drinkers. However, it might also be argued that heavy drinkers are less affected by alcohol at 300 mg/l BAC and that the implications of misses for these drivers are less critical. Further research is necessary to investigate the performance patterns of heavy drinkers and determine whether the Tracometer would be as effective in detecting this group of drivers at higher BAC limits.

CONCLUSIONS

The results of this study provide evidence that the Tracometer task is more effective than the CTT in detecting individuals with blood alcohol levels above 300 mg/l. It is concluded that this test device has considerable potential for use as an in-vehicle drunk driver countermeasure.

However, further research is clearly indicated to examine a variety of issues. An important issue that requires further research is test reliability. Are the results repeatable using the same and a different group of subjects? Further research is also necessary to determine the extent of training needed to achieve stable baseline levels for the Tracometer. More data is required spanning a wider range of BACs to determine failure rates at levels below 500 mg/l and above 1000 mg/l. One drawback of the Tracometer is the length of a trial. It takes an average of 2.5 minutes to complete one trial consisting of 100 movements. Further research is required to determine whether test presentation time can be reduced (to 30 seconds or so) without sacrificing test effectiveness. Finally, research is required to develop and test prototype devices which are compatible with vehicle instrument panel designs.

Continued research in this area holds the promise of developing an effective countermeasure to a traffic safety problem which has proven to be extensive and persistent.

ACKNOWLEDGMENTS

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APPENDIX A

TELEPHONE PARTICIPANT INTERVIEW FORM

Interviewer _____

Date _____ Name _____

Address _____

Phone _____ Best time to call _____

Age _____ Height _____ Weight _____

Vision Right _____ Left _____ (Corrected) _____

Availability _____

Current Drug Use (past 3 months) _____

Do you drink tea or coffee? _____ Total cups/day _____ .

Over the counter drugs? Yes _____ No _____

If yes, specify drug(s) and frequency of use _____

Prescription drugs? Yes _____ No _____ If yes, specify drug(s)

and frequency of use. _____

Tobacco? Yes _____ No _____ If yes, how many/day? _____

Marijuana? Yes _____ No _____ If yes, how often? _____

How much do you usually smoke? _____

Do you drink alcoholic beverages? Yes _____ No _____

Usual drink? _____

How much? _____ How often? _____

Subject Name _____

In the last two months have you used any of the following?
If so, how often?

	No	Once	Twice	Times/week
Amphetamines				
Barbiturates				
Cocaine				
Hallucinogens (LSD, peyote, psilocybin, etc)				
Quaaludes				
Sedatives				
Tranquilizers				
Other (Please list)				

Subject Name _____

General Health

Last Doctor's visit _____ Reason for visit _____

Any problems with the following:

Heart Kidneys Liver Ulcers Diabetes
Nervous Disorders Respiratory Coordination

Any problems with alcohol use such as the following:

Nausea Vomiting Dizziness Other

Will you be willing and able to abstain from your current drug
use Yes _____ No _____

Subject Name _____

A-3

Current Alcohol Use (past two months)

PUT ONE CHECK MARK IN EACH COLUMN:

	Wine	Beer	Whiskey Liquor	Any kind of drink
3 or more times a day				
2 times a day				
Once a day				
Nearly every day				
3-4 times a week				
Once or twice a week				
2-3 times a month				
About once a month				
Less than once a month but at least once a year . .				
Less than once a year				
Never had it				

How often do you have as many as 5 or 6 glasses (or cans)?

	Wine	Beer	Whiskey Liquor
*Nearly every time			
*More than half the time			
Less than half the time			
Once in awhile			
Never			

How often do you have as many as 3 or 4 glasses (or cans)?

	Wine	Beer	Whiskey Liquor
*Nearly every time			
*More than half the time			
Less than half the time			
Once in awhile			
Never			

How often do you have as many as 1 or 2 glasses (or cans)?

	Wine	Beer	Whiskey Liquor
*Nearly every time			
*More than half the time			
Less than half the time			
Once in awhile			
Never			

*Proceed to next beverage

Medical Examination for Volunteers in Research Projects

(to be completed by the Volunteer)

Last Name	First Name	Middle Name	Sex	Date of Birth		
				Day	Month	Year
Street Address			City	Province	Telephone No.	
Marital Status		Next of Kin		Address		
☐ Married ☐ Single ☐ Other						
Occupation			Social Insurance Number			

FAMILY HISTORY	LIVING		DEAD	
	Age if Living	State of Health	Age of Death	Cause of Death
Father				
Mother				
Brothers & Sisters				
Spouse				
Children				

PAST MEDICAL HISTORY

Is there a History of:	YES	NO	If Yes, Specify
Eye Trouble			
Nose or Throat Trouble			
Ear Trouble or Deafness			
Head Injuries			
Other Injuries			
Surgery			
Tuberculosis			
Epilepsy			
Mental Illness			
Kidney or Bladder Trouble			
Skin Disease			
Rheumatism or Joint Trouble			
Lung Disease			
Allergies			
Heart Disease			
Stomach Trouble			
Fainting Spells			
Headache			
Regular Alcohol or Drug Use			
Other			
FEMALES ONLY	YES	NO	
Menstrual Disorders			
Pregnancy			

Date of Last Menstrual Period _____

MEDICAL EXAMINATION

Height (cm) _____ Weight (kg) _____ Bp _____ Pulse _____
 Urinalysis _____

Is there any abnormality of:	YES	NO	If Yes, Specify
Head or Neck			
Ear, Nose or Throat			
Eyes, Eyegrounds			
Teeth, Gums or Mouth			
Skin or Scalp			
Lungs			
Cardiovascular System			
Abdomen			
Nervous System			
Genitourinary System			
Locomotor System			
Others			

Additional Remarks by PhysicianPHYSICIAN'S STATEMENT

This volunteer is ☐ acceptable ☐ not acceptable for the experimental project as stated.

Date

Signature of Examining Physician

VOLUNTEER'S STATEMENT

I, the undersigned hereby declare that the answers given on this questionnaire, by me, regarding my health history are correct to the best of my knowledge. Having been given a satisfactory explanation of the procedures of the experiment for which I am volunteering.

Date

Signature of Volunteer

Witness

SCREENING PHYSICAL EXAMINATIONS FOR RSU-84 SUBJECTS

A-6

Subject's name: _____ Age _____ yrs

Social Insurance Number _____ Tel 416 - _____ - _____

Chart: ON FILE IN ROAD SAFETY UNIT

HISTORY: Chart reviewed and no significant finding noted []

or _____

PHYSICAL EXAMINATION

Mean (n=3)

Weight _____ kg Skin Fold: Triceps _____ mm

BP _____ mm Hg S'iliac _____ mm

PR _____ per min S'scapular _____ mm

TOTAL ===== mm

NSF

Comment if abnormality noted:

Head & Neck [] _____

Chest [] _____

CVS [] _____

Abdomen [] _____

MSS [] _____

This subject is fit []

is not fit []

to participate in the above study.

date _____

R.C. Frecker M.D.

CONSENT FORM

A study of Alcohol Effects on Performance

I, _____, being of legal age for consent, hereby agree to participate in a research study designed to measure my ability to perform laboratory tracking tests under the influence of alcohol. I fully understand the purposes, risks and procedures of this study as they have been explained to me by the principle investigator, Mr. Ian Noy. Questions I have had concerning the study have been answered to my complete satisfaction.

I have been informed that no deceit is involved in the performance of any of the tests and I understand that what I am expected to do is perform as well as possible. I have been informed and understand that nothing whatsoever in the stimuli or responses can harm me.

I understand that I will return to the Road Safety on five separate occasions. On the first occasion I will be trained on the tracking tests. The training on the first day should take about 2.5 hours. On each of the four subsequent occasions, I will be asked to consume alcoholic beverages prepared in such a way as to raise my blood alcohol concentration to a prescribed level. On each of the four treatment days I can expect to spend a full day (8:30 to 4:40) at the laboratory. The maximum dose I may be required to consume is three drinks of 1.5 oz of vodka containing 40% alcohol by volume. This amount will raise my blood alcohol level to about 0.10% BAC. If I receive the maximum dose of alcohol, I may expect to feel lightheadedness, decreased coordination, mild nausea and later symptoms of mild hangover. From time to time, my blood alcohol level will be monitored using a breathalyzer. I will not be told the dose level. I will also be required to perform the tracking tests before and after dosing.

I agree to abstain from consuming the following substances prior to testing: marijuana for a period of one week; caffeine for 4 hours; food for 3 hours; and, tobacco for 1-2 hours. I further agree to abstain from the use of antihistamines during the study.

I understand that I shall be required to remain in the laboratory for a minimum of 3.5 hours after consumption of alcohol and until my blood alcohol concentration, as determined by breathalyzer analysis, has dropped to a level of 0.03% or lower. I understand that I will not be permitted to drive myself to my destination and agree to be driven home or to take a taxi from the laboratory on the understanding that the fare will be provided.

I understand that I will receive payment at the rate of \$15.00 for the time I spend on the training day and \$25.00 for each of the four treatment days. In addition, if I have fully complied with the above restrictions as evidenced by breathalyzer and urine tests, I will receive a bonus of \$100.00. I agree that I will be

paid upon completion of the study.

I understand that my participation in this study is contingent upon my being medically fit and I agree to inform the medical doctor or Principle Investigator of any change in my medical status, including the use of antihistamines or other drugs, which may have occurred since my medical examination. I further understand that I am free to withdraw from the study at anytime without prejudice. If I have any questions, I may ask them before or after I consent to participate in this study.

I understand that any and all personal information concerning me that is revealed in connection with this study will be kept in strict confidence except as data unidentified as to source.

I understand that I may expect no benefits from this study other than the payment of the stipulated fee.

Dated at Downsview this ____ day of _____, 1983.

Witness: _____ Subject: _____

SIN: _____

APPENDIX B

DETERMINATION OF FAT PERCENTAGE
THROUGH SKIN-FOLD MEASUREMENTS

The method is predicated on the fact that body density can be calculated by carefully measuring selected skin folds through the use of nomograms which have been built up for each age group and each sex. These nomograms represent thousands of measurements taken in various populations to compare body density measured by weighing under water (the standard technique) with body density calculated by the method given below. Appropriate correction factors are built into the calculations shown in these sheets.

A variety of sites may be chosen for skin-fold measurement but experience has taught that the highest reliability is gained through the use of the skin folds which are easiest to measure. One technique measures seven skin folds, another relies only on one (the triceps). We have chosen the three skin folds which show the least variation in repeat measurements -- the triceps (taken behind the arm), the subscapular (taken just below the shoulder blade), and the suprascapular (taken at the side just above the hip). The exact sites are described below.

It is helpful if the person taking the measurements, which are repeated three times, calls out the results to another person who then writes them down. This results in less bias being introduced in the measurement as it diminishes the chances of remembering the previous measurement for a particular site.

The instrument which is used for taking the skin-fold measurement (thickness) is called a caliper. There are various designs, but the principle is the same -- a known force is applied to pads of known area between which the skin fold is pinched. The thickness of the fold is read from a dial to the nearest 0.5 mm. The Harpenden caliper which we use is a precision instrument which can easily be damaged. Treat it with the care it deserves.

The limitations of accuracy are determined not by the instrument itself (it is quite accurate), but by the method of locating the skin fold and the method employed in taking the measurement. It is necessary to follow the following instructions carefully if accurate and reproducible measurements are to be obtained.

SUMMARY INSTRUCTIONS:

1. Ensure that the caliper is set to zero when the jaws are closed.
2. Take all measurements 3 times (in rotation) on the non-dominant (usually the left) side. Call results to scribe.
3. Measure the skin-fold thickness at the triceps, supra-iliac, and subscapular sites. Take the average of the three measurements for each site.
4. Calculate fat percentage as shown below.

TECHNIQUE FOR CALIPER MEASUREMENT OF SKIN-FOLD THICKNESS

The skin fold is picked up by pinching the skin and underlying fatty tissue and by pulling what is between the fingers away from the underlying muscle sufficiently to allow the caliper pads to be placed around the fold just below the pinching fingers (about 1 cm). Diagram 1 shows a skin fold being properly taken between the thumb and forefinger of the operator's left hand. Note the jaws of the caliper, and the pads which grip the skin just below where the skin is being held. The measurement is taken while the skin is still being pinched by the operator. A stable measurement should be achieved in most cases. Where the reading drifts gradually to a lower value, take the reading 3 seconds after applying the caliper -- but be sure that the drift is not to to slippage of the pads or to some change in the fold produced by relaxing or changing your finger grip. (Do not include muscle in the fold. If you are uncertain, have the subject tense the muscle group under the fold and reassess you strategy. The muscle must be relaxed again before the measurement can be taken.)

The folds are normally taken in the vertical plane, with the long dimension of the caliper pads also vertical. Departure from this method is permissible when the natural fold of the skin is other than vertical (such as the sub-scapular region). Sufficient pinching (thumb and forefinger) and pulling away of the fold from the underlying muscle is done to ensure that the sides of the fold are virtually parallel. Prolonged application of the caliper is to be avoided because this compresses the tissues and gives a falsely low reading.

Pull the skin fold out, and while still pinching apply the caliper 1 cm below the finger and thumb. Allow the jaws to close as much as they will (by releasing your grip while still holding the caliper). Take a reading to the nearest 0.5 mm; if the reading is drifting to a lower value, and you are certain of your technique, take a reading at 3 seconds after application. If some problem arises with the pinched fold, release the caliper, wait a minute, and repeat the measurement.

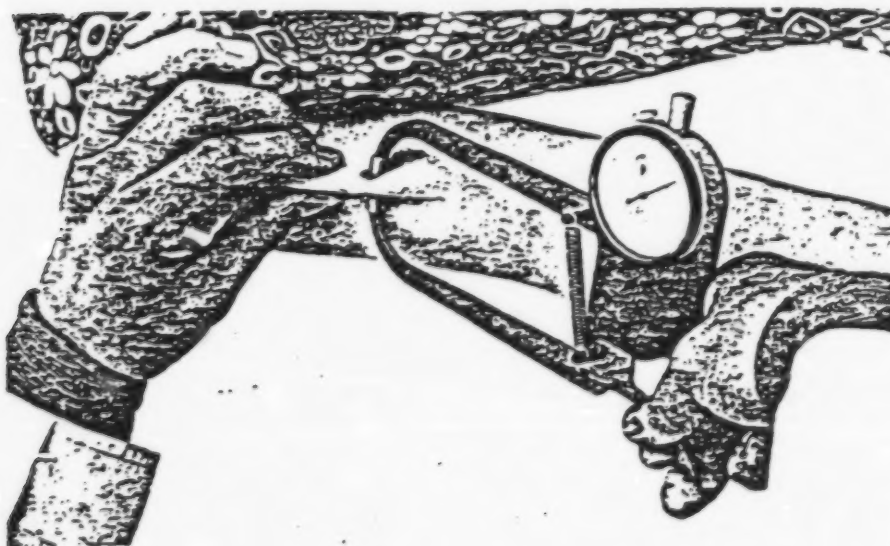
1. Take a triceps reading and record.
2. Take a sub-scapular reading and record.
3. Take a supra-iliac reading and record.
4. Repeat this sequence twice (3 reading in all for each site).
5. Average the readings for each site and record.
6. Calculate body density using formula below.
7. Calculate fat percentage using formula below.
8. Calculate lean body mass using formula below.

Record results and do calculations on page #5, which should become a permanent part of the subject's record.

(Various diagrams are shown on a following page which should be referred to until you become experienced.)

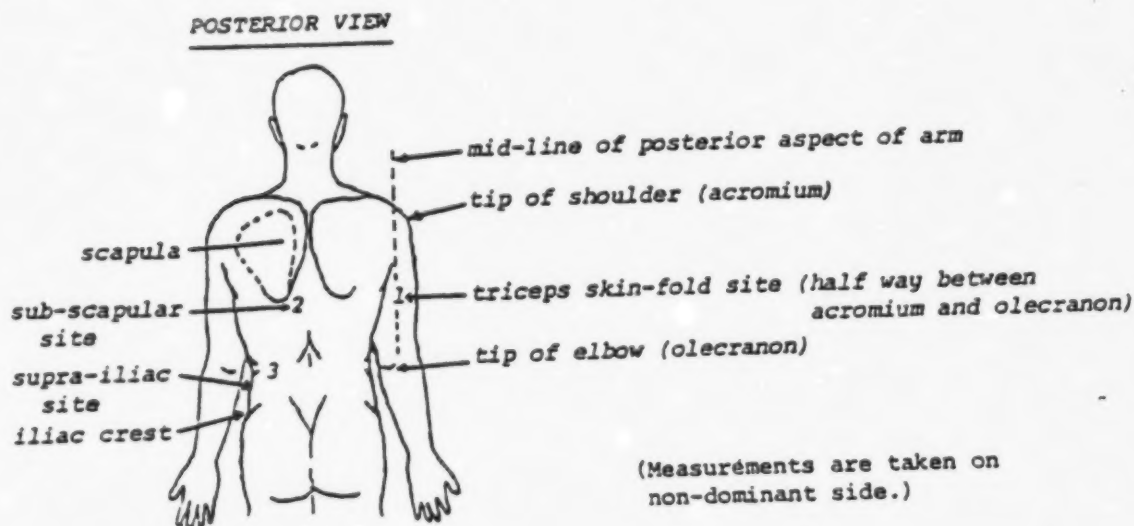
HOW TO TAKE A SKIN-FOLD MEASUREMENT *

The thumb and forefinger of the left hand are used to pinch and pick up a double thickness of skin with the underlying loose fatty tissue. The tissue (excluding muscle under all circumstances) is firmly pulled away from the site, sufficiently to cause the sides of the fold to become parallel, and to present below the fingers a fold which may be gripped between the pads of the caliper. The jaws of the caliper are opened by squeezing the handles, and the fold is pinched (as shown) by the pads of the caliper 1 cm below the fingers. The handles are released sufficiently to allow the full force of the Caliper to be exerted on the pads. A reading is taken from the dial to the nearest 0.5 mm. If the reading drifts to a lower value, and you are certain that your technique is correct, take a reading at 3 seconds after the jaws are allowed to close. Drift is usually caused by bad technique, but occasionally may be the result of true tissue compression. Three readings are taken and the average is used for calculations. The sites from which readings are taken are specified according to your particular experimental protocol.



Taking a skin-fold measurement.

TRICEPS, SUB-SCAPULAR, AND SUPRA-ILIAC SKIN-FOLD SITES



TRICEPS SITE:

(Site #1)

The triceps skin fold is located at the back of the arm midway between the outer tip of the shoulder and the posterior tip of the bent elbow -- i.e., midway between the acromial tip and the posterior pole of the olecranon.

A straight line connecting these two points should be marked (water-soluble marker) at its midpoint, and a horizontal line should be drawn around the arm to its posterior aspect. This is where the caliper pads should be applied, the finger/thumb pinch should, therefore, be 1 cm above this point. Use non-dominant arm.

SUB-SCAPULAR SITE:

(Site #2)

The sub-scapular skin fold is located just below and medial to the inferior pole of the scapula. The natural fold lies parallel to the medial edge of the scapula, running upwards and inwards from below the scapular pole. It should be pinched along its natural fold about 1 cm below and medial to the pole -- the finger/thumb pinch being taken somewhat above this. The fold is naturally loose and should easily be pulled away from the underlying muscle and bone.

SUPRA-ILIAC SITE:

(Site #3)

The supra-iliac fold is located above the iliac crest in the mid-axillary line, halfway between the iliac crest and the lower border of the rib cage. Its natural fold line is variable and should be followed. Again, it is usually fairly easy to raise a good fold in this location.

N.B.

ALL SKIN-FOLD SITES SHOULD BE CAREFULLY MARKED WITH A WATER SOLUBLE MARKER, AND REPEAT MEASUREMENTS SHOULD BE TAKEN AT PRECISELY THE SAME POINT, THREE TIMES.

CALCULATION OF BODY FAT PERCENTAGE

MEASUREMENTS:

Site	Reading #1	Reading #2	Reading #3	Average
Biceps	_____	_____	_____	_____
Sub-scapular	_____	_____	_____	_____
Supra-iliac	_____	_____	_____	_____

TSP TOTAL SKIN FOLD
(add averages)

CALCULATIONS:

The formula: $\% \text{ FAT} = \left(\left[\frac{4.95}{c - (m \times \log \text{TSP})} \right] - 4.5 \right) \times 100$

where: $c - (m \times \log \text{TSP}) = \text{body density} \times 10^3$

and: c and m are regression coefficients for age and sex specific populations (actual values are given below)

and: 4.95 and 4.5 are nomographic constants determined empirically through experimentation.

HOW TO CALCULATE FOR YOUR SUBJECT (STEP-BY-STEP):

1) Fill in the following for your particular subject:

age _____ sex _____ $m =$ _____ $c =$ _____ $\log \text{TSP} =$ _____

2) _____ $\times$ _____ = _____
(m) (log TSP) (Value "A")

3) _____ - _____ = _____
(c) (Value "A") (density)

4) (4.95) $\div$ _____ = _____
(density) (Value "B")

5) _____ - (4.5) = _____
(Value "B") (Fat Fraction)

6) _____ $\times 100 =$ _____
(Fat fraction) (Fat Percent.)

Fat Percentage =

TABLE OF REGRESSION COEFFICIENTS		
MALES	"c"	"m"
17 - 19	1.1555	0.0607
20 - 29	1.1575	0.0617
30 - 39	1.1393	0.0544
40 - 49	1.1604	0.0716
50 - 72	1.1689	0.0787
FEMALES	"c"	"m"
16 - 19	1.1517	0.0689
20 - 29	1.1566	0.0728
30 - 39	1.1397	0.0646
40 - 49	1.1278	0.0609
50 - 68	1.1298	0.0650

(Modified from Durnin & Womersley
[1974] Br.J.Nutr. 32:77-97)

Ethanol Dosing Schedule

That dose of vodka and orange juice (or tonic water) required to achieve a nominal "instantaneous" (peak) blood alcohol level (BAL) of 660, 925, and 1100 mg/l, after some 30 minutes of drinking of the prescribed BAC through the use of repeated, timed oral doses (based on 40% v:v spirits).

Peak concentrations are calculated assuming instantaneous distribution and no elimination. The desired concentration/time window is determined by assuming a clearance of 200 mg ethanol per litre per hour metabolic transformation; and by assuming that renal excretion is negligible by comparison. The clearance of ethanol is essentially zero order. The algorithm assumes there has been fasting for four hours previously.

G = Gross body weight (kg)

F = Fat fraction = Body fat/100

K = Dosing constant

for 500 mg/l = 1.81

for 800 mg/l = 2.51

for 1000 mg/l = 2.97

Vodka = $KG (1 - F)$ ml

Mix = 1.67 Vodka ml

Total dose (vodka + mix) to be divided into 3 equal drinks to be given over 10 minutes at 20 minute intervals.

